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The Water Requirement of Alfalfa

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ON IRRIGATED land in the western United States alfalfa is by far the most important forage crop. It probably occupies a larger acreage than any other one crop. It is not only cut for hay but is also pastured extensively. It is a perennial crop with a deep root zone and a long growing season. When grown for hay and adequately irrigated it may be cut at least three times in a season, even in the northern part of the country, and as many as seven or eight times in southern areas. On the other hand, if adequate irrigation water is not available the plants may survive a long drought, but growth is then restricted.

Probably because the alfalfa plant is able to survive and even to continue growth when its water supply is restricted, the opinion is widely held among irrigation farmers that in case of a water shortage the loss will be less if water is withheld from alfalfa than from most other crops. This is probably true. But it does not follow that alfalfa will grow and yield as well with a restricted water supply as with more copious irrigation.

From the standpoint of irrigation agronomics, information has been needed on two questions with respect to alfalfa: (1) Does the crop make more efficient use of water when irrigated sparingly or infrequently than when the water supply is continuously abundant? (2) Does the crop make more efficient use of water when the nutri-

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tional level of the soil is high than when it is low? These questions are important in any situation where irrigation water is scarce or expensive. It was the need for information on these two points that inspired the investigation here reported.

The efficiency of water use by the alfalfa plant may be evaluated by measuring the volume of water the plant draws from the soil in making a unit quantity of plant material. The term "water requirement" has come into general use as implying the quantity of water (e. g., pounds) transpired by a plant in making a unit quantity (e. g., 1 pound) of dry plant material. Thus the conditions of growth or of water supply that result in a lower value for water requirement are the conditions that give the greater efficiency of water use.

SUMMARY AND CONCLUSIONS

The investigation was conducted at the Rubidoux Laboratory, Riverside, Calif., with alfalfa grown in soil in large cans. The findings, as here reported, show that—

Under the climatic conditions at Riverside there are wide and consistent differences in the water requirement of alfalfa during the year. This requirement is lower in spring and early in summer than late in summer and in fall.

With three different regimens of irrigation, involving differences in the conditions of stress between the plant and the soil water, the rate of alfalfa growth decreased as the stress conditions were increased, but the efficiency of water use was approximately the same for all three groups.

THE EXPERIMENT

An experiment designed to answer the two questions stated above was formulated at the Rubidoux Laboratory, Riverside, Calif., in March 1941 and designated No. 57.[1] It involved the use of 12 galvanized iron cans, each 15 inches in diameter, 24 inches deep, and equipped with a drainage outlet near the bottom, which was covered with a layer of gravel. The soil with which the cans were filled was obtained from the grounds of the laboratory and was thoroughly mixed to insure uniformity as among the cans. Each can contained approximately 87 kilograms of dry soil, which, after being saturated with water and drained, held approximately 18 liters of water, of which approximately 4 liters was not available to plants. The moisture equivalent of the soil was 10.6 percent. Alfalfa seed was planted in the cans in May 1941, and the plants were subsequently thinned

[1] Acknowledgment is made to L. V. Wilcox, agronomist, for general supervision of the experiment; to George Y. Blair, assistant pomologist, for faithful and painstaking cooperation in its conduct; to John T. Hatcher, junior chemist, for the chemical analyses; and to Miles S. Mayhugh, senior scientific aide, for the photographs—all members of the staff of the Rubidoux Laboratory.

to a uniform stand for all cans, and three crops were taken off that year. The experiment began with the start of the fourth crop, on January 6, 1942.

The first objective was to determine whether the water requirement of alfalfa is influenced significantly by the regimen of irrigation. For this purpose, of the 12 cans used, 4 were allocated to each of 3 different irrigation treatments as follows: (1) Cans 5 to 8 were surface-irrigated infrequently, i. e., when the plants had used approximately all the available soil water and began to wilt; (2) cans 1 to 4 were surface-irrigated frequently, i. e., when the plants had used approximately half the available soil water; (3) cans 9 to 12 were subirrigated by maintaining, through the drainage tube, a continuously available supply of water in the gravel, so that the soil at the bottom of the can was always saturated. This part of the experiment was continued through crops 4 to 10, inclusive, from January 6 to November 14, 1942.

The second objective was to determine whether the water requirement of alfalfa is influenced significantly by the nutritional level of the soil solution. For this purpose, beginning with crop 12, on January 6, 1943, all cans were irrigated adequately to maintain optimum growth of alfalfa, but 6 of them (4 surface-irrigated and 2 subirrigated) were supplied with nutrient salts to establish and maintain a high level of nutrition; the other 6 were not so treated. This part of the experiment was continued through crops 12 to 25, from January 6, 1943, to November 22, 1944.

Throughout the time-period of the experiment each can was weighed frequently so as to measure the water lost by evaporation and transpiration and the water input was measured. The crop yields were weighed and the crop was dried to obtain the dry weight, and crops 11 to 25, inclusive, were analyzed to determine their composition. The plants were grown in a screened enclosure adjacent to the laboratory.

Seasonal Differences in Water Requirement

A review of the water-requirement data for the 3 years of the experiment shows that there were consistent seasonal differences. The data, assembled in table 1, show that the water-requirement values (pounds of water per pound of dry plant material produced) were much lower for the crops produced prior to mid-July than for those produced later in the year. For the year 1942 the mean of the water-requirement values for the first four crops was 619, and for the last three crops of that year, 1,159. For 1943 the respective mean values were 625 and 1,018, and for 1944 they were 523 and 928. Thus it appears that, under the climatic conditions at Riverside, alfalfa plants in making a unit of dry plant material use about 75 percent more

TABLE 1.—*Seasonal differences in the water requirement of alfalfa—experiment 57*

1942

Crop No.	Growth period	Irrigation treatment			Mean
		Infrequent	Frequent	Subirrigation	
		Pounds	*Pounds*	*Pounds*	*Pounds*
4	Jan. 6–Mar. 9	629	645	672	649
5	Mar. 9–Apr. 24	422	477	522	474
6	Apr. 24–June 2	577	656	587	607
7	June 2–July 6	680	855	702	746
8	July 6–Aug. 13	1,220	1,393	1,192	1,268
9	Aug. 13–Sept. 15	973	1,020	918	970
10	Sept. 15–Nov. 14	1,236	1,232	1,251	1,240

1943

Crop No.	Growth period	Irrigation the same for both groups		Mean
		Without nutrients	With nutrients	
		Pounds	*Pounds*	*Pounds*
12	Jan. 6–Mar. 27	524	524	524
13	Mar. 27–May 11	553	532	542
14	May 11–June 26	814	807	810
15	June 26–Aug. 3	979	924	952
16	Aug. 3–Sept. 9	1,072	1,012	1,042
17	Sept. 9–Oct. 16	1,078	1,041	1,060

1944

19	Jan. 8–Mar. 11	516	441	478
20	Mar. 11–Apr. 18	494	469	482
21	Apr. 18–May 31	501	489	495
22	May 31–July 15	672	604	638
23	July 15–Aug. 22	1,104	967	1,036
24	Aug. 22–Oct. 10	1,240	1,086	1,163
25 [1]	Oct. 10–Nov. 22	634	539	586

[1] Crop not mature.

water late in summer and in fall than in spring and early in summer. This finding indicates that intercomparisons as to water requirements should take into account the seasonal influences.

Effect of Irrigation Regimen

The aim of the study of the effect of irrigation regimen was to find whether the efficiency of the use of water by alfalfa, i. e., the water requirement, was essentially different when the plants were irrigated sparingly and forced to use approximately all the available soil water than when they were abundantly supplied with water all the time. The 12 cans of soil in the experiment were divided into 3 groups, made as nearly alike as possible, by selecting them on the basis of stand and of the growth behavior of the plants during the first 3 crops when all cans were watered alike.

A different irrigation treatment began with the fourth crop, on January 6, 1942. One group, cans 5 to 8, was irrigated only when

the weights showed that the available soil water was approaching depletion, or when the plants began to wilt. Because the cans were exposed to the weather and received rain during the winter months, some of the crops did not exhaust the available soil water. But during the summer months each crop of this group used all or nearly all the available soil water two or three times during its period of growth.

The irrigation regimen for the second group, cans 1 to 4, was such that water was added when the weights showed that 50 to 60 percent of the available soil water had been used. These plants never

FIGURE 1.—Representative alfalfa plants of each of three groups having different regimens of irrigation—crop 5, March 9 to April 24, 1942: *A*, Infrequent surface irrigation; *B*, frequent surface irrigation; *C*, subirrigation.

showed symptoms of water shortage. In the third group, cans 9 to 12 were each equipped with an outside supply of water connected with an input tube near the bottom and so controlled that the lower layer of the soil was always saturated. The daily volume of input for these cans was measured. A representative of each of the three groups of plants is shown in figure 1.

The crops were harvested from all cans on the same day, generally when the plants of any one group had come into full bloom. There were differences in the stage of growth among the groups at harvest-time, and these may have influenced slightly the water-requirement values.

It should be pointed out that the term "water requirement," as it was first used, implied the quantity of water transpired by plants in making a unit quantity of dry plant material. It did not include any water that might be evaporated from the soil, because the plants were grown in covered cans to prevent such evaporation. In this experiment the cans were not covered and there was certainly some loss of water by direct evaporation from the soil and some loss also by evaporation from the plants after a rain. As here used, the term "water requirement" involves all water dissipated from the system, both by evaporation and by transpiration; the term in this sense is believed to be applicable to field conditions.

The part of the experiment that involved differences in the regimen of irrigation was continued during most of the year 1942, from January 6 to November 14. During that period seven crops were harvested. The findings in respect to these crops are summarized in the first part of table 2. The entries show for each group (1) the mean volume, in liters, of water dissipated by evaporation and transpiration from each can for the growth period of seven successive crops; (2) the mean weight, in grams, of the dry plant material produced by the seven successive crops; (3) the relative crop yields of groups 2 and 3 as compared with that of group 1; and (4) the water-requirement values for each group, i. e., the grams of water used for the production of 1 gram of dry plant material.

TABLE 2.—*Summary of crop yields and water requirements of alfalfa for 3 successive years—experiment 57*

Crop	Growth period	Treatment	Water dissipated per can	Yield, dry weight, per can	Yiele increase	Water requirement
			Liters	*Grams*	*Percent*	*Pounds*
4–10	Jan. 6–Nov. 14, 1942	Infrequent irrigation	398. 5	536. 5		743
		Frequent irrigation	627	789. 5	47	794
		Subirrigated	862. 7	1, 105. 2	106	781
12–17 [1]	Jan. 6–Oct. 16, 1943	Without nutrients	605	754. 4		802
		With nutrients	682	860. 7	14	792
19–25 [1]	Jan. 8–Nov. 22, 1944	Without nutrients	607. 5	860		706
		With nutrients	755. 5	1, 143. 1	33	661

[1] Irrigation for crops 12–17 the same as for crops 19–25.

It is obvious from the tabulated data that the alfalfa plants made more growth in the cans that were irrigated frequently than in those in which most of the available soil water was used before the next irrigation. Also it is evident that in the soil that was subirrigated continuously the growth was by far the best. This evidence appears to show that not all the available soil water is used by plants with the same facility. In the case of the plants of group 1 the recurring periods prior to irrigation, when the soil contained less than half its total available supply of water, made conditions that retarded plant growth, as compared with the condition of less water stress that existed in the soils of the other two groups.

Notwithstanding these striking differences in the rate of plant growth that were associated with the different conditions in respect to the available soil water, the actual efficiency with which the plants used the available water was about the same in all three groups. This is indicated by the narrow range in the water-requirement values from 743 to 794. It is possible that the actual differences in the efficiency of water use may have been less than these values would indicate, because of the fact that the reported water-requirement values include the water lost by evaporation from the soil surface. The cans of group 2 were watered at the surface much more frequently than those of group 1, and therefore the actual evaporation losses were probably greater. On the other hand, in cans of group 3 the surface soil was wetted by rain only, so that during the rainless summer the surface soil remained dry and the evaporation loss was probably less than that of the other groups.

This first part of the experiment provides an answer to the first of the questions stated above, viz: Does the alfalfa crop make more efficient use of water when irrigated sparingly or infrequently than when the water supply is continuously abundant? The answer is no. But this part of the experiment shows definitely that with sparing or infrequent irrigation the growth rate of alfalfa is retarded and the yield reduced. The evidence supports the view that within reasonable limits the quantity of alfalfa hay produced is directly related to the volume of water used by the plants. Therefore, lack of adequate irrigation water does not increase the efficiency of water used by the alfalfa plant, but it does diminish the yield of hay.

Effect of Different Levels of Nutrition

The second part of the experiment was designed to show whether the efficiency of water use by the alfalfa plant is influenced by the level of nutrition in the soil solution. For this purpose the 12 cans used in the first part of the experiment were divided into 2 groups of 6 cans each by taking for one 2 cans from each of the original 3 groups and using the remainder for the other. In making the selection the stand and growth behavior of each can was considered, so that the two groups would be as nearly alike as possible. Included in each group were 4 cans that had been surface-irrigated during the first part of the experiment and 2 that had been subirrigated. Throughout the duration of the second part of the experiment the surface-irrigated cans were watered alike and at such frequency as to keep the available soil water above half its total volume. The subirrigated cans were continued on the same regimen as formerly of maintaining saturation in the bottom layer of the soil.

In order to obtain two different levels of nutrition as between the two groups of plants, the cans of group 2 were supplied from time to

time with a dilute solution of the salts calcium nitrate, potassium nitrate, magnesium sulfate, and potassium dihydrogen phosphate in the proportions (millimoles per liter) of 5, 5, 2, and 1, respectively.

The cans of group 1 were supplied with rain water and tap water only. The volume of the nutrient solution to be supplied to the cans of group 2 was not predetermined. Instead the solution was applied at such times and in such quantities as seemed indicated by the appearance of the plants. The aim was to obtain vigorous growth but not to injure the plants with excessive salt concentrations.

The application of nutrient salts to the cans of group 2 was begun with crop 11, of which the growth period was from November 14, 1942, to January 6, 1943, but it may be assumed that the effects were not immediately shown. Furthermore, it was desired to have the growth periods of 1943 correspond with those of 1942. Consequently, the data for crop 11 are not included in the summary of table 2. During 1943 the alfalfa crops were cut six times, crops 12 to 17. The application of the nutrient salts stimulated growth in the cans of group 2.

For the season of 1943 the cans of group 2 yielded 14 percent more than those of group 1, but the plants of group 2 also used more water than those of group 1, so that the mean water-requirement values for the two groups were nearly the same, i. e., 802 pounds for group 1 and 792 for group 2.

The experiment was continued through the season of 1944, with the occasional addition of nutrient salts to the plants of group 2.

FIGURE 2.—Alfalfa grown at two different levels of nutrition with the same irrigation regimen—crop 21, April 18 to May 31, 1944: Cans *A* and *B* had no nutrient salts; cans *C* and *D* had been fertilized.

The summary table omits the data for crop 18, which grew from October 16, 1943, to January 8, 1944. During 1944 seven crops were produced between January 8 and November 22. The plants of group 2 yielded 33 percent more than those of group 1, but again the mean water-requirement values were not far apart, i. e., 706 for group 1 and 661 for group 2. Two representative cans of each group are shown in figure 2, with the alfalfa ready to cut.

The evidence from this part of the experiment bears on question 2 stated above: Does alfalfa make more efficient use of water when the nutritional level of the soil is high than when it is low? The answer is yes, but the difference is not very great and may not be significant. For each of the crops 11 to 25, inclusive, the water requirement was lower for the plants of group 2 than for those of group 1, although for some of the crops the differences were small.

Effect of Nutrition on Crop Composition

In view of the fact that the plants of group 2 were abundantly supplied with nutrient salts containing nitrogen, potassium, and phosphorus, it might be expected that they would be richer in these constituents than the plants of group 1, which were not so fertilized. To obtain information on this subject the alfalfa tops as harvested from each crop were composited and analyzed in respect to eight constituents, not including phosphorus. The data of table 3 show the analytical findings for the plant material from crops 19 to 25, inclusive,

Table 3.—*Composition of alfalfa tops, crops 19 to 25, 1944—experiment 57*

GROUP 1—WITHOUT NUTRIENTS

Crop No.	Growth period	Dry weight per can	Calcium	Magnesium	Sodium	Potassium	Chloride	Nitrogen	Boron	Silica
		Grams	*E.p.m.*[1]	*E. p. m.*	*E. p. m.*	*E. p. m.*	*E. p. m.*	*E. p. m.*	*P.p.m.*[2]	*P. p. m.*
19	Jan. 8–Mar. 11	102. 6	726	183	195	587	213	2, 524	68	1, 356
20	Mar. 11–Apr. 18	129. 3	626	216	205	508	202	2, 204	52	2, 870
21	Apr. 18–May 31	166. 6	621	195	220	437	170	1, 925	51	1, 532
22	May 31–July 15	185. 3	668	178	226	343	156	1, 761	55	1, 865
23	July 15–Aug. 22	120. 7	678	205	242	381	172	1, 877	73	1, 618
24	Aug. 22–Oct. 10	90. 8	718	230	327	356	223	2, 273	83	2, 385
25	Oct. 10–Nov. 22	64. 3	636	211	388	473	287	2, 367	61	1, 371
	Mean	122. 8	668	203	258	441	203	2, 133	63	1, 857

GROUP 2—WITH NUTRIENTS

19	Jan. 8–Mar. 11	129. 0	684	184	158	731	175	2, 539	65	1, 516
20	Mar. 11–Apr. 18	145. 6	608	222	153	688	195	2, 343	52	2, 961
21	Apr. 18–May 31	194. 5	593	202	171	570	170	1, 995	50	1, 530
22	May 31–July 15	251. 3	656	194	179	479	174	1, 811	56	1, 764
23	July 15–Aug. 22	183. 1	654	195	183	533	183	1, 804	74	1, 545
24	Aug. 22–Oct. 10	142. 1	714	218	238	556	210	2, 116	82	2, 203
25	Oct. 10–Nov. 22	97. 2	647	210	262	727	242	2, 257	58	1, 539
	Mean	163. 3	651	204	192	612	193	2, 124	62	1, 865

[1] E. p. m. = Equivalents per million (of dry plant material).

[2] P. p. m. = Parts per million (of dry plant material).

both for group 1, not fertilized, and for group 2, to which the nutrient salts were applied. The mean values for each group of plants show that although the dry weights of the crops of group 2 were 33 percent higher than those of group 1, the mean values for the several constituents were nearly the same except for sodium and potassium.

For the plants of group 1, which were not fertilized, the sum of the values (equivalents per million) for sodium and potassium is 699, of which the value for potassium is 63 percent. In the case of group 2, the fertilized plants, the sum of the values is 804, of which the value for potassium is 76 percent. The inference that may be drawn from these facts is that with an abundance of potassium available in the soil solution the alfalfa plants take up more potassium than when this constituent is less abundant, as in the soils of group 1. Furthermore, it seems evident that at the lower nutritional level the plants take up a larger proportion of sodium than when more potassium is available.

The fact that the plants of group 2 were supplied with a nutrient solution containing potassium and that their potassium content was nearly 40 percent higher than that of the plants of group 1 should not be taken to indicate that the soil solution was rich in potassium. It was not. Several times during the course of the experiment the cans that were surface-irrigated were given more water than the soil could hold, in order to obtain drainage percolates for analysis. In these samples of the percolates the actual concentrations of the salt constituents were influenced by the volume of the percolate and these volumes were not the same for the two groups of cans. But the relative concentration of the constituents in any percolate would not be greatly influenced by differences of volume.

Analysis of the percolates included determinations of the three nutrient constituents nitrate nitrogen, potassium, and phosphorus. The details of the analysis are not reported, because the differences in the volumes of the percolates make comparisons difficult. It may be said, however, that the percolates obtained from five different crops show (1) that the concentrations of the three nutrient constituents were consistently low, i. e., generally less than 0.2 equivalent per million; (2) that there were no consistent differences in the concentrations as between the percolates of the two groups; and (3) that although in the plant material the potassium concentration was higher than the sodium, these relations were different in the soil solution as sampled by the percolates. In the percolates the sodium concentration was usually more than 100 times greater than that of potassium.

With respect to the other basic ions in the percolate solutions the concentrations of calcium were approximately the same as those of the sodium; the magnesium was generally about half as much; the chloride concentrations were about the same as the magnesium; and the boron ranged narrowly from 0.3 part per million (p. p. m.) upward.

The conditions of concentration in the percolates that were analyzed show that the nutrient constituents were quickly absorbed from the soil solution and that the observed differences of plant growth as between the two groups were not associated with corresponding differences in the soil solutions as represented by the percolates.

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